The Technology of Climate Adaptive Building Shells (CABS) In Improving Environmental & Economic Efficiency

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Abstract:

Designing buildings with high environmental and economic efficiency has recently become very difficult, and the ecological problems of the whole world have become realistic and require radical solutions. As 20 - 60% of the total energy used in buildings is affected in their enclosures design and construction, consider adopting sustainable energy efficiency strategies in their design and construction. In the past, factors such as society, economy, and technology influenced architecture, prompting architects to develop innovative design theories, particularly after the industrial revolution and the devastation it left in the environment, such as pollution and natural resource consumption, as well as the phenomenon of heat islands. In addition, many factors such as society, economy, and technology led to the idea of active adaptive smart buildings emerged as these factors have provided technological advances in electrical control systems, computer engineering, information technology, artificial intelligence, electronic science and materials science, opportunities for the use of motor building systems in architecture and its components.

Therefore, it introduced the concept of active, interactive, moving and adaptive facades instead of the traditional fixed facades, which are characterised by interacting with the surrounding environment through many technologies that improve the economic and internal environment of the building and its efficiency to make the building sustainable. CABS work with the concepts of adaptability, versatility, and evolution. This paper aims to provide a comprehensive review of the research, design and development efforts in the CABS system field. Based on the study of the theoretical framework, a classification is made to place a variety of concepts in one context. Thus, a measurement ruler is reached that includes an essential vocabulary and indicators that can characterise the CABS so that the research can measure its level of effectiveness in the examples selected.

Keywords: adaptive facades, CABS, economic efficiency, environmental efficiency, adaptability, sustainable energy.

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Introduction :

In recent decades, the design of environmental and energy-saving buildings has become in two main directions: first, the active technologies are used to raise the sustainability of the built environment, which use the innovative technologies that generate and provide renewable energy; second, the technologies that used the transformation of natural resources to be more efficient.

To achieve sustainable goals, we should review the building skin design because it has considered one of the most effective elements of sustainability. Also, traditional building skin is designed to provide only shelter and protection, which is often made by making it insensitive to the environment, isolated and dependent on mechanical and electrical systems to achieve comfort requirements for its occupants at the expense of energy consumption and depletion of non-renewable natural resources.

The building envelope is defined as a boundary between the interior and exterior environment, which is affected by environmental factors changing throughout the year. In addition, the traditional envelopes cannot respond to ecological changes, so the climate-adaptive envelope is designed to be responsive to the surrounding environment changes. Also, to make the building's internal environment from an environmental manufactured to a natural environment, it needs to integrate the active technology (material technology, Internet Tech, sensing technology, etc.) with passive design technologies. The aim of the study is to review and analyse the components and features of adaptive envelopes that exceed traditional examples in environmental and economical treatments by studying their technologies, systems and components and thus reach an appropriate definition of them and their most essential indicators and vocabulary, and make a measuring ruler through which to measure the level of adaptation of those envelopes, to reach the most important results and recommendations that help to develop it.

Literature Review:

(Loonen, R.C. et al., 2013) showed that the widespread application of Climate Adaptive Building Shells promises to contribute profoundly to achieving high energy performance goals. Therefore, it recommends the need for future research and solutions to other future challenges in this area. Also, it focused on the need for further analysis of the technologies currently developed and creating new design solutions to create more responsive and adaptable building covers through multidisciplinary studies. Bacha, and Bourbia, Pointed out the importance of the building envelopes design as an essential factor in creating a sustainable and energy-efficient construction; the study focused on PV modules which used in facades and concluded that these envelopes had a big impact on improving indoor air temperature and thermal and visual comfort levels. Khadraoui and Sriti noted that the double-skin facade simulated interface gives thermally acceptable results under study conditions. Also, the results confirm that these shells are a protective layer separating external and internal environments whose performance depends on multiple physical and conceptual factors. She pointed out that developing intelligent materials helped create an adaptive casing capable of changing in response to changing conditions.

Therefore, the research can reach an essential vocabulary and indicators in the technology of buildings shells to achieve the best results in sustainable aspects by making it a measure of study through which global built examples are measured.

Approach and Aims:

1. Review and analyse the components and features of adaptive smart envelopes that surpass traditional examples in environmental, energy and thus economic treatments.
2. Come up with an appropriate definition of adaptive smart envelopes.
3. To reach the essential components, techniques and vocabulary of adaptive smart building covers.
4. Make a ruler measure the adaptation of building envelopes.
5. To reach the most important results and recommendations of the research.

Concept of Adaptation:

Adaptation as a linguistic term refers to changing something to fit a purpose or position to fit into its surroundings. Adaptation, as a scientific term borrowed from biology, means that organisms try to cope with the natural factors that surround them to be able to follow the life and prevent its yard so that they create properties that make them more willing to conform to the conditions of the surrounding environment, but the concept of adapting the system is through its ability to adapt to environmental conditions by including many technologies inspired by living natural systems and studying and applying the mechanisms that have made them successful and adapted to their surrounding environment.

Climate Adaptive Building Shells (CABS):

By U.S. Energy Information Administration, residential and commercial buildings are responsible for approximately 72% of energy consumption per year. Also, 20 to 60% of all energy used in buildings is affected by the design and construction of building skins. So, to reduce the increased demand for energy for artificial lighting and improve internal daylight levels to overcome restrictions on existing traditional facades, the idea of an active shell has been proposed as an adapted element by exploiting the benefits of advanced technologies. The active envelopes can manage indoor environments by dynamically modifying their properties and being responsive to external environmental factors. They are caused by thermal glare, energy efficiency in lighting, the value of thermal resistance, combined efficiency in solar heat gain, thermal energy efficiency, response to solar patterns, comfort level for occupants, and negative ventilation. Studies have shown that these modifications can improve the performance of the active interface by 40 to 65% compared to static envelopes (Matin. et al., 2017, P. 25).

In 1969, the cyber design theory was proposed by Gordon Pasek to apply the electronic concept in architecture. In addition, the functional theory suggests designing dynamic architecture instead of static designs by using active installations in building components to achieve rich interactions between humans and their environment.). (Romano. et al., 2018, P.66), (Matin. et al., 2017, P. 24).

Hence, the responsive, adaptive moving envelope system began as a sustainable response to environmental stimuli so that the occupants of the building are provided with real-time and continuous thermal and visual comfort in keeping with the ecological changes surrounding them.

As for (Banham), he has developed three traditional patterns that can characterise the building envelopes to be effective and successful in general, which are (conservation, selectivity and renewal), and in recent decades, interest in the issue of energy management has emerged as a new generation of packaging has appeared that is characterised by conditioning and interactive, which aims to reduce The net energy consumption of buildings, which makes them have an energy consumption rate that may reach zero in order to improve comfort and sustainability in buildings and cities (Romano, et al. 2018, P.65). Then a fourth new style emerged for the building envelopes (adaptation). These adaptive casings can actively control energy flow between indoor and outdoor spaces. Moreover, it can adapt its components to maximise indoor comfort and reduce energy consumption. Several different types of adaptive envelope concepts have already been developed, which can ensure improvements in building energy efficiency and economy through its ability to change its performance and behaviour in real-time according to the internal factors of the environment, through materials, components and systems. Thus, the envelopes of these buildings can contribute significantly and be viable to achieving sustainability goals in improving their internal environments. (Romano, et al. 2018, P.66). Adaptive envelopes must therefore be able to provide thermal mass control insulation, radioactive thermal exchange, ventilation, energy management, solar lighting, solar shading and moisture control. Accordingly, the cover isolates the building from its outer perimeter only when necessary, can produce energy, and remains or airs when interior comfort requires it. Thus, the envelopes of adaptive buildings act as the building's environmental supervisor.

Adaptive smart envelopes built in recent years in many developed countries can be distinguished by their high-tech covers by having control and control systems that make them an essential component of the advanced smart building system that controls and improves their internal environment and provides comfort to their users.

Adaptive Smart Envelope Technologies:

Designing buildings with high environmental and economic efficiency has recently become very difficult, and the ecological problems of the whole world have become realistic and require radical solutions. As 20 - 60% of the total energy used in buildings is affected in their enclosures design and construction, consider adopting sustainable energy efficiency strategies in their design and construction. Also, previously factors such as society, economy, and technology influenced architecture, prompting architects to develop innovative design theories, particularly after the industrial revolution and the devastation it left in the environment, such as pollution and natural resource consumption, as well as the heat island phenomenon. In addition, many factors such as society, economy, and technology led to the idea of active adaptive smart buildings emerged as these factors have provided technological advances in electrical control systems, computer engineering, information technology, artificial intelligence, electronic science and materials science, opportunities for the use of dynamic adaptive building systems in architecture and its components.

Gradually, the covers of adaptive buildings evolved and varied until they came to carry many names such as active, interactive, advanced, dynamic, responsive and interchangeable. It was also found that all of them carried the characteristic of adaptation. Many technologies have been used and evolved in the building skin, through studying and knowing them and understanding the details of their mechanisms; We can discover the transformation of building envelopes from ordinary intelligence to practical, adaptive, interactive, dynamic, etc., intelligence. As the most important technologies are as follows:

1. Movement technology:

The kinetic envelopes can define (facades and ceilings, which are characterised by their ability to move by providing them with technologies that make them mobile and able to respond to the surrounding conditions), thus gaining the characteristic of adapting with the surrounding environment. (Elmokadem et al, 2018. P.757), The concept of moving envelopes revolves around their ability to change geometry to create movement in space. This movement affects the physical structure or characteristics of the physical system without damaging it. There are a lot of classifications of the movement of moving envelopes, and we find the most common ones that depend on the transformation or change of the body of the cover. As shown in Figure 1, moving envelope elements can be moved into space in four geometric methods (IBRAHIM. et al, 2019. P.3):

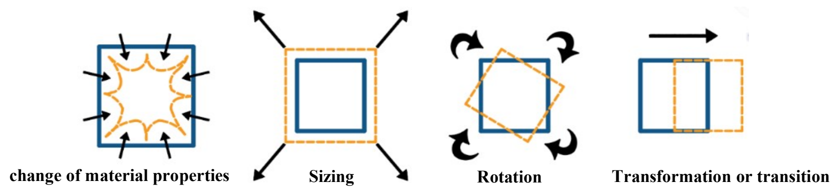


Figure NO. (1), Methods of movements elements and components of kinetic interfaces, Source: Researcher's Work

Movement techniques are divided into two types. The first one called mechanical system, which includes interconnected mechanical elements such as pulleys, wheels, joints, wheels, cables and gears. These complex and bulky mechanical parts are considered legacy products of the Industrial Revolution, which used external forces to create transitional or rotational movements in building envelopes (Matin, et al , 2017, P.6).

The second one is called the electromechanical system, which consists of electrical elements that operate the mechanical parts automatically; in addition, this system contains sensors for various factors such as temperature, pressure, humidity, air etc., and in some advanced buildings, this system is connected to the Internet. After 2001, electromechanical engines were developed into air engines. Hydraulic motors became typical components of adaptive envelopes responding to climatic conditions, as in the building of the sea towers, which used centralised control systems programmed based on regional weather data and data received from sensors, such as those that sense touch, temperature and light.

Passive technology in Adaptive Smart Envelopes:

The beginning of the emergence of alternative technologies for the encapsulation of smart buildings was when the Passive approach was used to design responsive, adaptive envelopes. Based on this design approach, the interface's reliance on electric and manual power has been eliminated, and natural resources such as wind, water and sunlight have been used as energy sources. It consists of several technologies, consisting of integrated PV structures and double-layer envelopes, as well as envelopes containing structural systems that move due to their response to surrounding environmental impacts such as wind movement. This technology has achieved the thermal comfort of the building as well as the proper ventilation of its spaces (Attia. et al, 2020. P. 3262).

2. Control System Technology and Sensors in Adaptive Smart Envelopes:

The control system consists of a device or set of devices that manage the movement of building elements or building systems, ordering, directing or regulating their activity (Elkhayat, Y.O., 2014. P.824). Controlling the mobile building system to make it responsive and interactive with the surrounding effects is one of the basics that is focused on during the design and implementation phase, as the control system consists of two elements:

1. **Input:** made by different sensors and input methods that give extra information about the surrounding environment. There are five methods of introduction:

a) **Manual input:** Commands are given directly by the individual operator without needing other control methods such as pressing a key to run or close.

b) **Sensors and detectors:** It is used to collect information and data that support the operating system.

c) **Information previously entered:** the building control system uses previously entered system information, such as recorded data that can be returned to make the necessary decision without needing sensors, such as time decisions rather than the surrounding environment.

d) **Manual programming:** Used according to the operating conditions of the building, the building control system is adjusted by the building officials according to the comfort of the occupants so that it corresponds to all different circumstances.

e) **Internet:** The internet control system can be connected to additional information such as climate and others and updates related to the control system used in the building by the manufacturer.

2. **Controllers:** It is worked by the computer, which is responsible for the decisions that receive information from the input systems and give instructions to the operators that manage the different elements of the building and the control systems building elements can be classified to:

a) **Internal Controls:** It is divided into smaller control systems that give element systems priority in decision-making and enable them to work within the building, as they have a material capable of changing its shape by increasing change in size and transformation ability. (Fox, M.A. et al., B.P., 2000. P.96), (Elkhayat, Y.O., 2014. P.824)
b) **External Control:** it works by the ability of the building elements to make decisions either on their own or from another source that has power, such as elements that move through manual control (Elkhayat, Y.O., 2014. P.824).
c) **Complex Control :** It is a combination of two systems that can make decisions either by themselves or using inputs and are classified into four types (Elkhayat, Y.O., 2014. P.824):
1) **Direct Control :**It is transmitted directly through a motor system that obtains energy from multiple energy sources, whether electrical, manual, by humans or has a biomechanical change according to external environment variables (Elkhayat, Y.O., 2014. P.824), (Abdul Wahhab. et al., 2020. P.8272).
2) **In-Direct Control**: The movement is indirectly caused by sensors' action with external information, then sensors send the message of data-shaped to the control system, which orders the opening or shutdown of power sources that operate devices or engines to produce the reaction required to move the building elements (Elmokadem et al, 2018. P.753), (Abdul Wahhab. et al., 2020. P.8272).
3) **Responsive In-Direct Control:** This system is similar to the previous type, but controllers can make decisions to open or close the power sources managing the building elements based on information inputs from different and multiple sensors planted in the parts of the building (Abdul Wahhab. et al, 2020. P.8272), (Elmokadem et al, 2018. P.753).
4) **Heuristic, Responsive In-Direct Control :**

This working system depends on individual response sensors, which have the ability to learn within the mechanical system through the successful experimental response, which leads to obtaining experience in responding to different external environmental variables, so the system will enter the time factor within its calculations where it stores old data and its results according to the circumstances that occurred and the success of these results, becoming a database that uses by the control system that makes the building capable of learning and adapting to the circumstances affecting it and this is the highest level of intelligence for smart and dynamic architecture until this moment (Abdul Wahhab. et al, 2020.), (Elmokadem et al, 2018.).

There are many ways to control the building elements of adaptive smart envelopes, such as internal control, external and direct-complex control which contains sensitive smart sensors or distributed on the building and indirect-complex control through multiple and different sensors, the control systems will control on the building envelopes' work and movement to make them responsive to environmental and human variables, especially when using Heuristic, Responsive In-Direct Control that makes the building system has the learning ability and experience and makes it rise to a greater degree of intelligence, which transforms the building and its parts from responsive to adaptive, these technologies are the latest technical developments to control the movement of the building.

3. Smart Materials Technology in Climate Adaptive Building Shells:

Advances in materials science have provided opportunities for other entrances to design adaptive envelopes with advanced responses, which provides opportunities to use the material instead of mechanical or electromechanical components. These technologies are not internal or exterior of the building but are directly integrated with its building materials. Material-based engines rely on molecular changes in material structures when stimulated by external signals such as light photons, temperature changes, chemicals, magnetic field forces and electricity flows. Material movements are generated by changes in size, shape, colour, liquidity and electrical currents. There are many smart materials, such as alloys. These polymers have a memory of the shape, electrically active polymers, and variable properties materials, which act as engines and sensors in the structure of those responsive envelopes (Attia. et al, 2020. P. 3261), (Matin, et al, 2017, P.17). Therefore, material technology does not require any external sensors or control systems, also smart material responses to environmental variables are stable, limited and unprogrammable. Smart materials can be classified by function or technique to:

- **Intelligent Materials that Change Properties:** Those materials that can change their properties such as a colour (thermally, mechanically, chemically or electrically way) or change their flow, for example (nanomaterials and electrical materials), or those that change their state such as (liquid crystals or materials with suspended particles).

- **Smart Energy Reflective Materials**: It is materials that reflect the energy by taking energy from their natural or industrial sources and then reflecting and storing it in the form of electrical energy such as (PV, electrothermal, and thermal exchange) (Ahmed, W. et al., 2019.P4).
- **Energy-Converted Smart Materials:** Those materials can convert the energy from one type to another, such as (photovoltaic, thermal converter, photovoltaic converter, managed converter, electrically or magnetically transformed) (Sirajuddin. 2018، P.15).

Based on what was presented previously in development of technologies. can note that mechanical and electromechanical components have provided the envelope system with an effective and sustainable approach to design. However, this active approach has been replaced by a passive technical approach due to defects in mechanical, electromechanical systems, such as their need for maintenance, in addition to the use of advanced information technologies and the use of sensitive sensors, as well as intelligent materials, and the extent of the development they have provided adaptable and responsive buildings shells which depending on the impact of surrounding environmental variables. The Role of Climate Adaptive Building Shells in improving the efficiency of the building.

Climate Adaptive Building Shells in improving building efficiency:

The contemporary approach to architecture is defined by energy efficiency and environmental responsibility that offers new designs, functional patterns and building technologies as Steve Jobs' following phrase: (Design is not just about the shape or look. but also how it works). Innovative concepts of contemporary architecture are designed to meet many requirements such as energy efficiency, environmental friendship, advanced material use and user satisfaction. Therefore, it is essential to design and develop buildings envelopes by making them interactive and ideally responsive to environmental and human variables so that we can improve two aspects of building efficiency:

1. **Environmental Aspect:** Adaptive smart envelopes are known for their ability to modify their shape, look, direction or control of their openings by automatically responding to environmental variables, such as temperature, humidity, wind, etc.; this system can reduce glare unwanted, the intensity of solar radiation and providing the building with ventilation through their movement, shape geometric change or change in the characteristics of its material (Attia. et al., 2020. P. 3264).

2. **Economic Aspect:** By achieving positive results in the environmental aspect, we can observe a significant improvement in the energy consumption of the building, thereby increasing the economic efficiency of the building due to the low energy consumption (zero energy consumption), in addition to some buildings taking the approach of storing and saving energy to the adjacent neighbourhood, and this approach has a significant impact on the sustainable development of built environments.

Accordingly, we conclude that the kinetic shading units used in smart adaptive envelopes reduce the energy consumption for lighting, cooling and heating. Can increase the efficiency of the building. By developing the models and concepts of these envelopes, their effectiveness can be enhanced in automatic context responses, including the environment and building occupants, using smart technologies to obtain the occupants' comfort environment and raise the building's efficiency.

4. IT in Climate Adaptive Building Shells:

Information technology has changed the way of electromechanical systems control. It was a breakthrough in promoting the principle of adaptive envelopes with the addition of a feature of taught-self to the building. The idea of the control system in responsive envelopes used the microcontrollers for controlling the shell elements, as mentioned. Local sensors provide data to the computer for processing and then send it to microcontrollers to manage the work of building envelopes elements. Although this technology is brilliant, its operations are vulnerable to computer failure and cybersecurity risks.

Climate Adaptive Building Shells features:

Essential features of Climate Adaptive Building Shells features are:

1. The ability to move in response to the effects surrounding the building.
2. The ability to sense ambient external influences such as solar radiation, wind and others.
3. The ability to control, manage and regulate the movement of the building envelope components.
4. The ability to self-taught the building, providing accumulated experience over time.
5. It has flexibility.
6. Has the ability to improve the building's environmental efficiency.

7. Has the ability to improve the building's energy efficiency.

Conceptual Framework:

After the theoretical presentation, this study reached into several indicators, including technological aspects and sustainable aspects of the technology of adaptive smart envelopes in different types. It concluded that the best and most advanced solution to solve the environmental problems of buildings and strengthen the economic aspects. Then, the research reached the following primary and secondary vocabulary, note figure NO. (2):

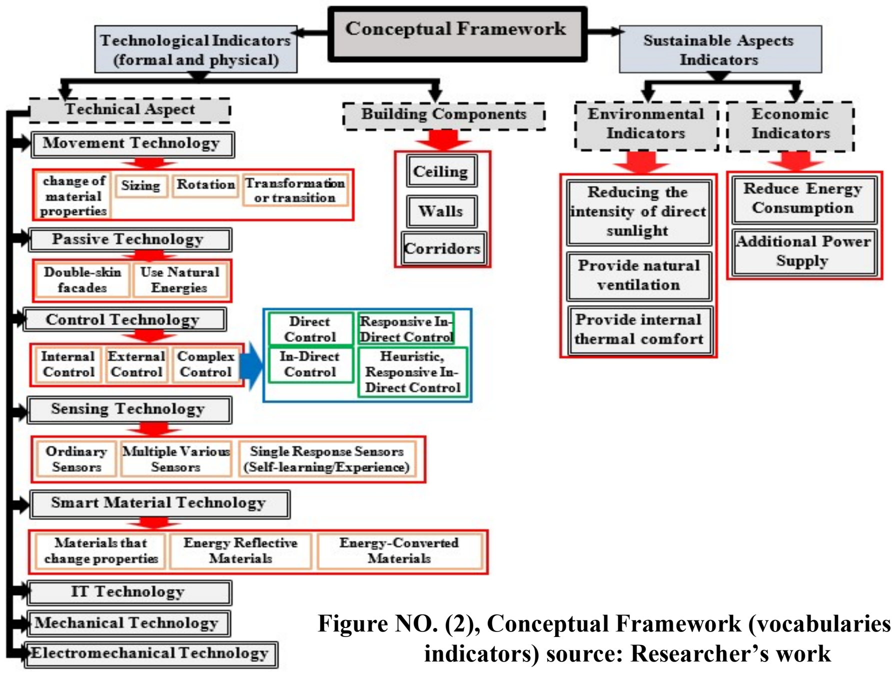


Figure NO. (2), Conceptual Framework (vocabularies and indicators) source: Researcher's work

Based on the vocabulary of smart technologies applied to the adaptive building shells, this vocabulary will be tested on different samples of executed global buildings with adaptive smart shells as follows:

Project NO. 1/ Agbar Tower:

The tower is one of the essential tall buildings in Barcelona - Spain. It is a building dedicated to the Barcelona Water Company, with a height of 142 meters, with 34 floors, with four floors below ground level. The project is considered one of the applications of climate architecture, as it harnessed the climate and surrounding conditions to reduce energy consumption and improve the environment for its users. https://www.tecnospa.com, the envelope is designed in a double way, as it consists of two elements: the structure and the outer shell. The tower also consists of two oval cylinders that are not concentric, topped by a glass dome represented by the roof to complement the outer shell. The internal cylinder includes the vertical and horizontal movement of the building and the services linking the floors (1-31) where there are no columns. The external cylinder contains two layers; the first internal consists of insulating concrete about (0.5m), which is covered with aluminium panels, to increase thermal resistance; also, there are 4500 double-glazed windows which help to balance daylight and heat gain as well as promote natural ventilation. The other surface contains 59,619 panels of automatically moving glass curtains fixed on an aluminium frame, making the building envelope a transparent cover. The envelope also has advanced LED technology and about 4,500 coloured light units and can be controlled through digital tower systems. In the middle between the two cylinders, there is a space that allows the movement of natural air, which enhances the ventilation and reduce the temperature of the building by making it work like double-skin facades. (Vassigh, S. et al., 2011, P33-34), https://www.tecnospa.com. They used environmentally friendly materials that reduce pollution, in addition to materials that store Solar energy by up to 25.11%. https://www.designbuild-network.com, note Figure No. (3) and tables NO. (1), (2).

Name	**Agbar Tower**
Execution date	**2004**
Location	**Barcelona- Spain**
Architectural	
Building type	**Administrative office**

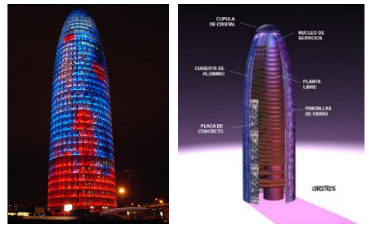
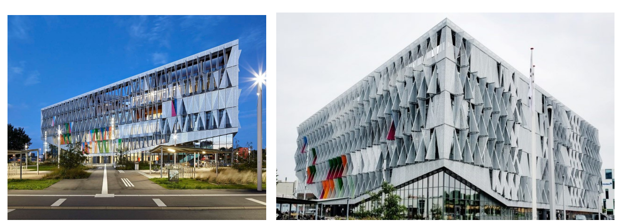


Figure NO. (3) the Tower of Akbar in Barcelona 2004, source: http://architecturalmoleskine.blogspot.com

Project NO. 2/ SDU Campus Kolding:

The building took the shape of a triangle, with a total area of (13,700 m2), with a height of five floors. It is a multi-purpose facility consisting of classrooms and social spaces at the University of Southern New Denmark. The building has applied high sustainability standards through innovative, intelligent technologies. https://moam.info, note Figure No. (12). The project was distinguished by many sustainable technologies, as the facades provide solar shading by providing 1,600 movable triangular solar panels made of perforated aluminium, installed on the skin in a way that allows it to adapt to the external climatic conditions and the internal user behaviour. The provision of optimum daylight gave interior spaces a comfortable environment, making the building flexible throughout the year. It becomes more open in the winter when the sunlight is less or closes more in the late spring when the sun is low. The triangular elements contained a simple organic pattern of circular perforations, giving the building a dynamic effect from the outside and a play of light and shadow from the inside. In this way, the building envelope design achieved the optimum balance between the amount of light and energy allowed to flow in and out. It also includes passive technologies such as a combined heating and cooling pump that uses groundwater to regulate the temperature in all building parts also low-energy ventilation system uses natural night ventilation in the central hall and solar energy cells to store energy. https://commons.wikimedia.org. The project used sensors that measure light and temperature levels and constantly mechanically regulated the shell elements employing a small motor. A mechanical enclosure system is a form of kinetic solar shading with an environmental strategy designed to reduce total energy demand by 50% compared to similar buildings in Denmark and reduce annual energy consumption to 36 kWh/m2 in just one year. note figure No. (4) and tables NO. (1), (2).

Name	**SDU Campus Kolding**
Execution date	**2012-2014**
Location	**Denmark-Kolding**
Architectural	**Henning Larsen**
Building type	**Educational Institution**



Form No. (4) University of Southern Denmark SDU Campus Kolding in 2014,
Source: https://www.emtmmaster.net

Project NO. 3 / One Ocean - Thematic Pavilion EXPO:

Expo in Youssou, Seoul, South Korea, 2012 embodied the idea of "ocean and living coast" expressed through the design of a soft and dynamic multi-layered exhibition suite. Its design aimed to create an iconography that would integrate with its urban context and surrounding nature with an area of 5,657 square meters. It made it similar to fish, with moving panels made of fibreglass-reinforced polymers (GRPF). This technology demonstrates the possibility of combining natural movement mechanisms well, which has been a success. The exterior of the suite embodies the idea of the building's transformation and constant change inspired by the sea.

This increased the social interaction between the building and its users, making it a strong attraction. The innovative moving adaptive cover proposed in the competition was developed in line with electronic principles (including automated units) with the help of engineering consultants (Knippers-Helbig) from Stuttgart, confirming the expo's innovative and environmental approach. The use of wind allows for better natural ventilation of spaces air-conditioned which has been introduced into vertical areas across the floor. During the day, the elements of the kinetic façade control the entry of solar radiation heat. Also, solar panel units are used on the roof to provide the building with energy. The climatic characteristics were also thoroughly analysed and simulated by Transsolar to reduce energy consumption and increase the efficiency of the building, which helped to reach the environmental goal of the building thoughtfully and practically to ensure its success https://www.architectandinteriorsindia.com. The façade is about 140 m, with a height of 3-13 m. and consists of 108 panels that are supported by motors at the top and bottom of the edge of the façade. Plates are made of fibreglass-reinforced polymers (GRPF), which combine high tensile strength with low bending rigidity, allowing significant flexible reflectable distortions. A plate engine is a spiral spindle operated by a support engine (servomotor). A computer controls this shading system as biometric panels are associated with geometry, movement and light: when the single board is more extended, the opening angle wider - the light-affected area will be more significant. During the day, the moving elements of the skin are operated by controlling the panel engine to regulate the entry of natural light into the showroom and thus become an environmentally comfortable area for display activities. Individual opening and closing control allow the movements to be designed for wave-like patterns. After sunset, the opening moves were visually improved by LED lamps installed on the inner side of the tablet chips. Thus, the kinetic and adaptive shell has become a subtle combination of technical innovation in line with the exhibition's ideologies. See figure NO.(5) and tables NO. (1), (2).

Name	**EXPO Pavilion**
Execution date	**September 2010 - April 2012**
Location	**Seoul - South Korea**
Architectural	**Soma Lima**
Building type	**Exhibition - Entertainment**

Project NO. 4 / Hanwha Headquarters Remodelling:

The Hanwha Tower in Seoul, South Korea, executed in 1980, has been developed according to the surrounding environment. As the old building facades did not reflect Hanwha's corporate identity as a visionary for the future in innovation and energy, the company needed to represent its commitment to sustainability better. The renovation included a redesign of the exterior facades, interior courtyard facades, lobbies, meeting rooms and the surrounding landscape. In order to achieve sustainability aims, the concept of the adaptive envelope was developed, as it works to improve the internal environment of the existing building, as well as interact with the building's control system programs on the one hand and with the site within its context on the other. Previously, the initial facade of the tower consisted of panels in the form of opaque horizontal bands and single layers of dark glass. Upon renovation, the insulated glass was replaced with an aluminium frame to improve the daylighting and exterior view of the building, note Figure No. (6). The choice of frame materials and specifications largely depended on the sun and steering factors to ensure user comfort inside and reduce energy consumption. The new facades were also designed with techniques that make the northern facade open to enable daylighting inside the building, while it was designed darker on the southern front due to the impact of the sun on the building's heat load. The glass was installed at an angle that distances it from solar radiation to reduce the solar effect. At the same time, the upper part of the southern facade is tilted at an angle close to direct sunlight. The window-to-wall ratio achieved 55% transparency across the entire face. Photovoltaic cells were placed on opaque panels on the south and southeast facade to gain as much solar energy as possible. Also, LED units were placed with dimming elements for the southern facade, in addition to energy-generating photovoltaic cells that gave the facade dynamics. The project achieved a 35% reduction in the building's annual carbon dioxide emissions and a 40% reduction in its annual energy consumption. The solar panels produce enough excess energy to equip 200 residential houses Hanwha Headquarters Remodeling - UNStudio. Economic factors were considered during the design, as they consolidated structural features on a large part of the shell and excluded double-curved surfaces throughout the design resulting from the links of both Korean culture and parametric computer technology https://www.unstudio.com, note tables NO. (1), (2).

Name	**Hanwha Headquarters Remodelling**
Execution date	**2013**
Location	**Seoul - South Korea**
Architectural	**UNStudio**
Building type	**Administrative**


Before


After

Figure NO. (5) , Hanwa Tower, before and after the renovation, source: https://www.hanwha.com

Project NO. 5 / Lisbon Wood Building:

The Lisbon Wood apartment building was built in 1970, then redesigned in 2019, To give it a new life, according to the designers, through advanced technologies. In the past, it was a building for government services, and then it was neglected and turned into an abandoned building. The building was rehabilitated using smart materials and additional spaces, as well as connecting it to the international network of the Internet, which turned it into a smart building, thus creating new functions for the modern building, such as housing and commerce. After the renovation, the area of the building became 3882 square meters. The building, consisting of ten floors above the ground level, contained 15 apartments, two shops, gardens, a gym and a spa, and two underground floors for parking. The design team used materials according to their thermal comfort, durability and longevity characteristics. The new casing used thermally modified wood, which is the hallmark of the building; Being a traditional and noble material, it accepts contemporary technology. Design for the building a dynamic facade that gives different shapes and configurations at every moment of the day and for each apartment; Being constantly in motion, making the building changeable by adapting it to the surrounding environment. The new façade featured shading elements in automatic movable shutters made of an anodised aluminium frame covered with steel elements, then a thermally modified wood layer. It is also foldable with a unified automation control system, which leads to its opening or closing according to environmental factors and gives the building privacy for the interior spaces in terms of both environmental and visual. It also improves the energy efficiency of the building. Note Figure No. (7) and tables NO. (1), (2) https://www.archdaily.com ، https://www.anteprojectos.com.

Name	**Lisbon Wood Building**
Execution date	**2019**
Location	**Lisbon-Portugal**
Architectural	**Pedro Ferreira & Helena Vieira**
Building type	**Residential**


Before


After

Figure NO. (6) , Lisbon Wood Building, Source: www.Town Hall Hotel/rare |ArchDaily

Project	Technological Aspect																											Points
	Movement Technology				Passive Tech.		Control Technology						Sensing Technology			Smart Material Technology			Intern-et Tech.		Mecha-nical Tech.		Mecha-nical Tech.		Envelope Components			
									Complex Control																			
	Transformation or transition	Rotatio	Sizing	change of material properties	Double-Skin Facade	Use Natural Energy	Internal Control	External Control	Direct Control	In-Direct Control	Responsive In-Direct Control	Heuristic, Responsive In-Direct Control	Ordinary Sensors	Multiple Various Sensors	Single Response Sensors (Self-learning/Experience)	Materials that change properties	Energy Reflective Materials	Energy-Converted Smart Materials	Used Tech	Unused Tech	Used Tech	Unused Tech	Used Tech	Unused Tech	Ceiling	Walls	Corridor	
Agbar Tower		•		•	•	•	•					•			•	•	•	•	•				•		•	•	•	15
SDU Campus				•	•	•	•			•	•				•			•	•		•		•			•	•	13
Pavilion EXPO	•	•	•	•	•	•	•					•			•	•			•				•		•	•	•	15
Hanwha Headquarters	•					•	•					•			•	•		•	•				•			•		10
Lisbon Wood	•	•	•		•		•					•		•		•			•		•		•			•		12
	Sustainable Aspects																											

Project	Environmental Aspects			Economic Aspects		Points
	Reducing the intensity of direct sunlight	Provide natural ventilation	Provide internal thermal comfort	Reduce Energy Consumption	Additional Power Supply	
Agbar Tower	•	•	•	•	•	5
SDU Campus	•	•	•	•	•	5
Pavilion EXPO	•	•	•	•	•	5
Hanwha Headquarters	•	•	•	•	•	5
Lisbon Wood	•	•	•	•	•	5

Table NO. (1) Measurement Indicators for The Technical & Sustainable Aspects of Projects, Researcher's Work

Project	Technological Aspect Points	Sustainable Aspects Points	Final Total Points
Agbar Tower	15	5	20
SDU Campus Kolding	13	5	18
Pavilion EXPO	15	5	20
Hanwha Headquarters	10	5	15
Lisbon Wood	12	5	17

Table NO. (2), Final Total Points of Examples, Researcher's Work

Extracting the final results from the analysis of examples:

The results from the usage of vocabulary and Indicators for the technologies and environmental and economic sustainable aspects of an adaptive smart envelope in the projects above showed that the Tower of Agbar and EXPO Pavilion had the highest value, which is (20) points, then The University of Southern Denmark got (18), followed by the sequence the Lisbon Building (17). Finally, Hanwha's headquarters got (15). Note figure NO. (7).

The research concludes the advantage of using smart technologies in building envelopes, in addition to including most components of the building (roof, walls, shading corridors), to ensure the efficiency of its internal environment to achieve sustainable environmental and economic goals. As smart technologies were applied in most of the components of Akbar Tower and the Expo, they obtained the highest points from the technical and sustainable sides.

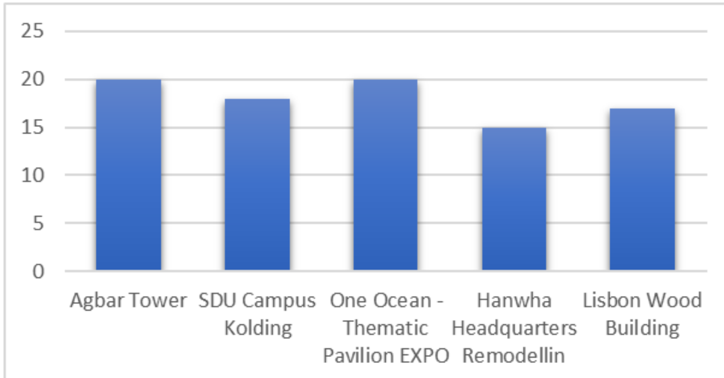


Figure NO.(7), The comparison of the results obtained with the global projects, researcher's work

Conclusions:

1. Applying adaptive smart envelops to buildings is an ideal solution to improve the building's environmental efficiency, whether existing or recent. AS it makes the temperature of the ambient and indoor air appropriate by controlling the building's isolation from solar radiation and healthily promoting the building's ventilation for its occupants, thus achieving environmental comfort for them.
2. Adaptive smart envelopes can raise building efficiency economically by improving the efficiency of the internal environment, which leads to a reduction in the energy spent on air conditioning. They can also store energy and supply it to the building later.
3. The best technology for using the latest control and sensing technology in adaptive smart skin is (self-taught).
4. Most buildings that have incorporated all possible shading elements into their cover (ceiling walls and other shading elements) have achieved high and successful levels of environmental efficiency.
5. The project's success lies in achieving the environmental and economic goals by making it more effective, responsive and adaptive to the surrounding environmental conditions.
6. It is recommended to redesign the shell encapsulating an existing building that is not environmentally qualified with an adaptive smart envelope to raise its environmental efficiency.

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